



# Presentation outline

- Introduction and methodology
- Natural variability based on NWP reanalysis and climate model data
- Deriving IR instrument requirement
- Summary and Conclusions



# Introduction

- Quantify natural variability and derive the calibration requirement for geophysical constituents observation
  - Methodology outlined in BAMS paper by Wielicki et al.
  - Derive Natural variability of  $T(p)$  and  $H_2O(p)$  from MERRA and ECMWF reanalysis data
  - Climate model (CMIPS-5) provides additional validation
  - Derive vertical  $T(p)$  and  $H_2O(p)$  accuracy required for trend detection using natural variability and autocorrelation length
- Derive spectral dependent instrument requirement using fingerprinting method and the required actuary for  $T(p)$  and  $H_2O(p)$ 
  - Frame work of the fingerprint method used
  - Fast radiative transfer model (PCRTM) is suitable for simulation study
  - Ill-condition due to vertical minimized by using EOF representation of the vertical profile.



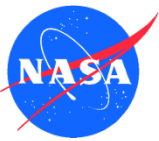
# **Part I**

## **Natural variability of Temperature and Water Vapor vertical Profiles**



# Temperature and humidity variability

- Detection of anthropogenic influence requires accounting for natural climate forcing
  - Internal forcing
    - EL Niño-Southern Oscillation (ENSO)
    - Quasi-biennial oscillation (QBO)
  - External forcing
    - Variation of solar irradiation (11 year cycle)
    - Major Volcanic eruption (EL Chichón in April 1982 ,Pinatubo in June 1991)
- Multiple linear regression (MLR) method is used to derive a linear trend term
  - Proxies for ENSO, QBO, volcanic eruption and Solar cycle signal from time series data
- Non-polar globally averaged, de-seasonalized monthly mean values from reanalysis results are used
  - Also done analysis of global and regions average with similar conclusions



# Climate forcing proxy indices

- Adopt proxy indices that are widely used for various global and zonal trend studies.
- I. Multivariate ENSO index (MEI) is used to represent global ENSO impact.
- II. NOAA/ESRL QBO index (from the zonal average of the 30mb zonal wind at the equator as computed from the NCEP/NCAR Reanalysis).
- III. Sun spot number (SSN) is obtained from NASA's Marshall Space Flight Center website.
- IV. Global stratospheric aerosol optical depth (AOD) data from NOAA is used to estimate Volcanic aerosol effect.



# Calibration requirement

Calibration requirement is established base on how the measurement uncertainty affect the climate trend detection uncertainty

$$U_a^2 = 1 + (\sigma_{cal}^2 \tau_{cal} + \sigma_{instru}^2 \tau_{instru} + \sigma_{orbit}^2 \tau_{orbit}) / (\sigma_{var}^2 \tau_{var})$$

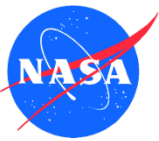
$$\sigma_{cal} = \sqrt{\frac{(U_a^2 - 1) \sigma_{var}^2 \tau_{var} - \sigma_{instru}^2 \tau_{instru} - \sigma_{orbit}^2 \tau_{orbit}}{\tau_{cal}}}$$

$$\sigma_{cal} = \sqrt{\frac{(U_a^2 - 1) \tau_{var}}{\tau_{cal}}} \sigma_{var}$$

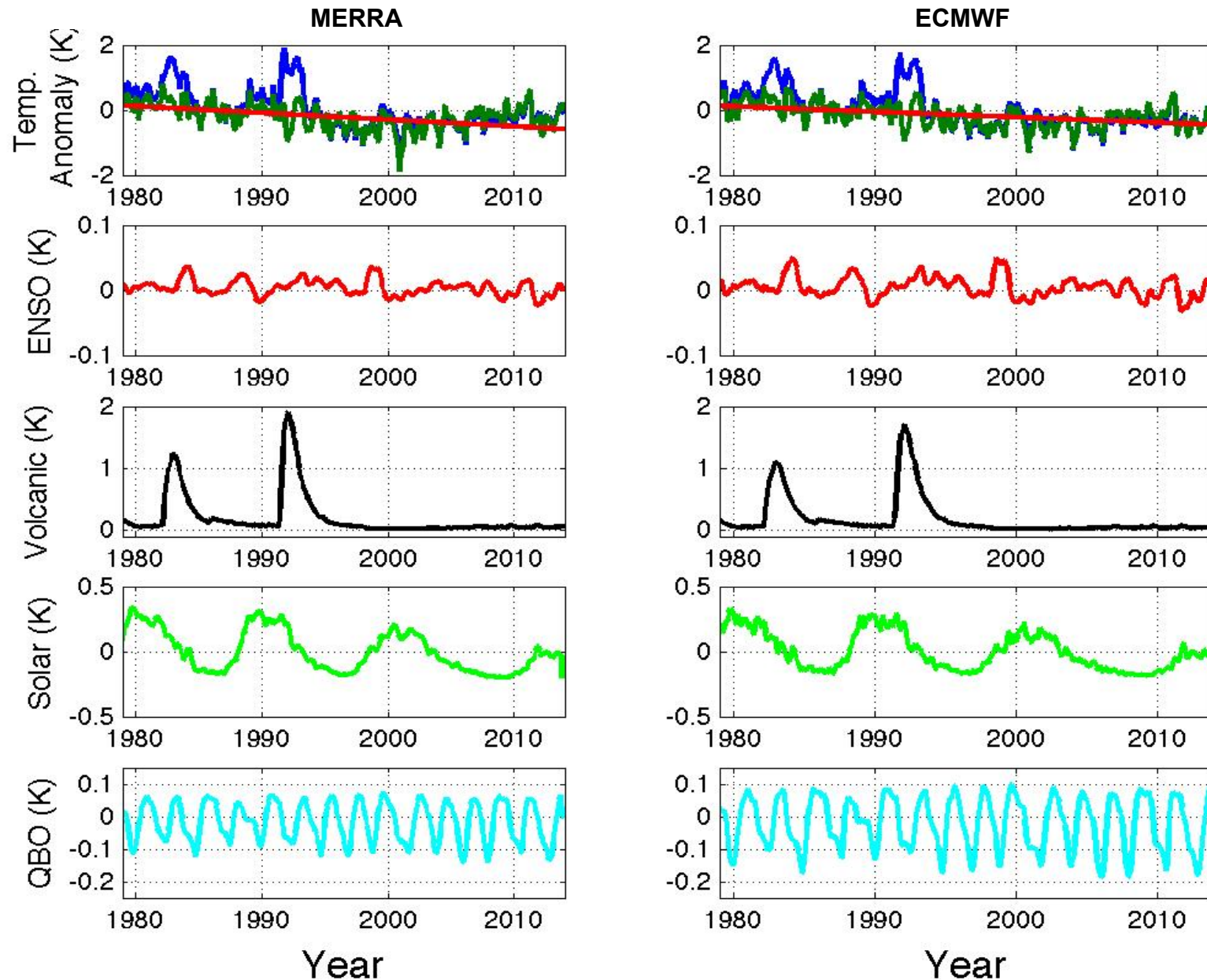
- instrument noise contribution  $\sigma_{instru}$ , is small due vertical averaging
- orbit sampling error  $\sigma_{orbit}$ , is also neglected

Accuracy uncertainty factor  $U_a$  (Wielicki et al. 2013) defines how CLARREO's observation accuracy for climate trends deviates from the accuracy of a perfect system

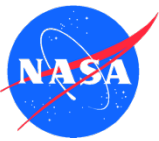
Bruce A. Wielicki, et al., 2013: Achieving Climate Change Absolute Accuracy in Orbit. *Bull. Amer. Meteor. Soc.*, 94, 1519–1539.



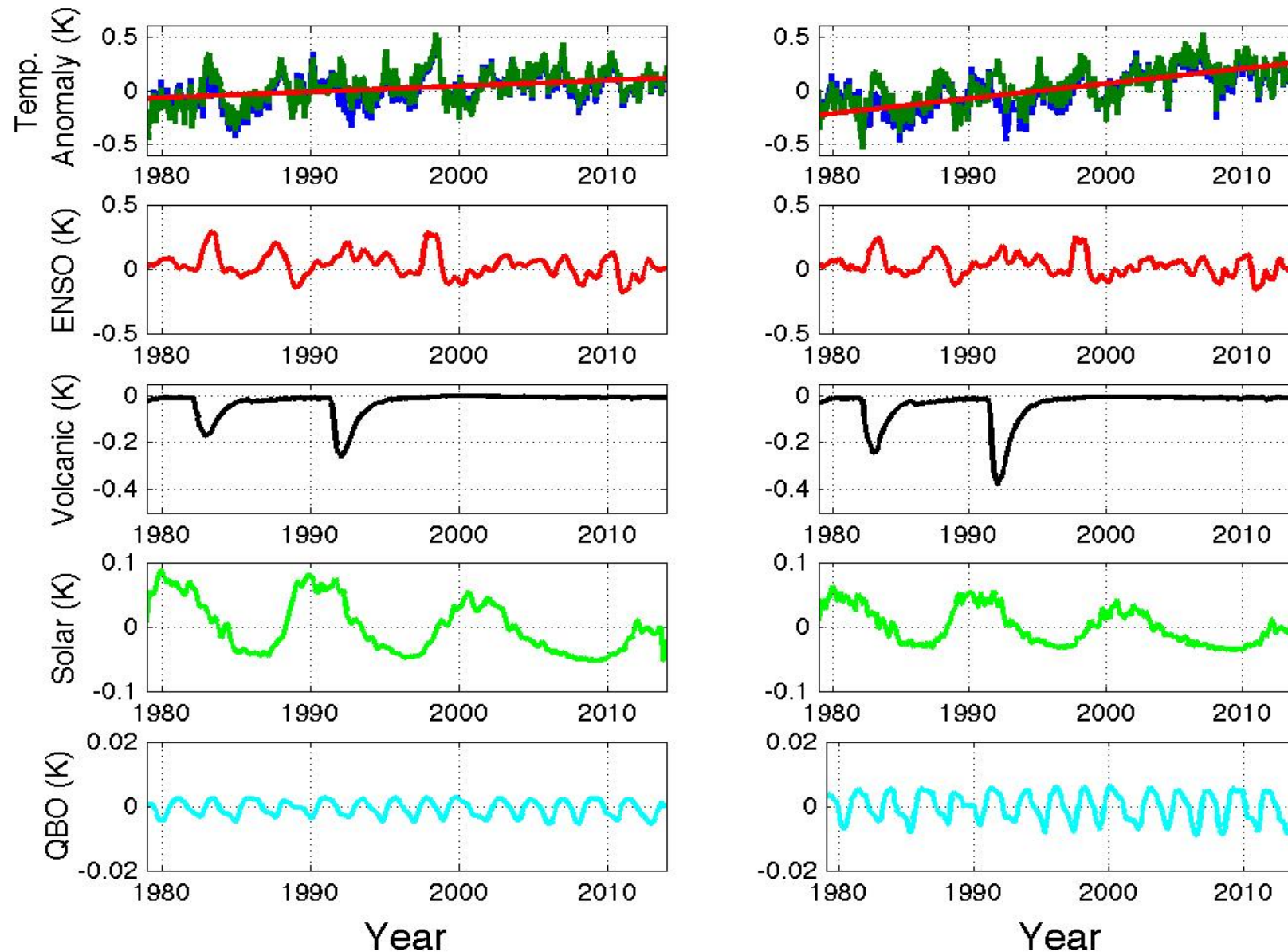
# Temperature anomaly and linear trend @ 70hPa from MERRA and ECMWF







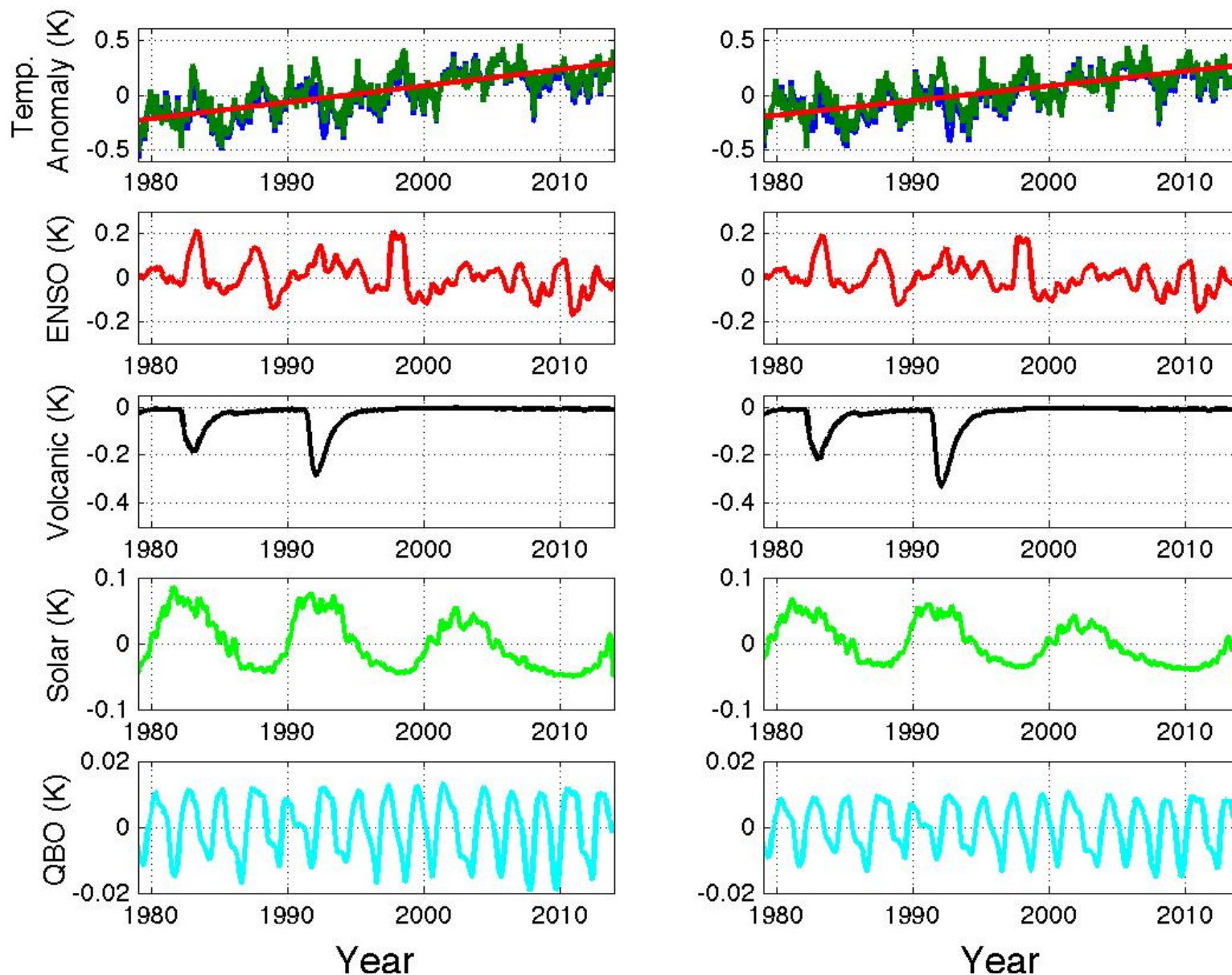
# Temperature anomaly and linear trend @ 975hPa from MERRA and ECMWF





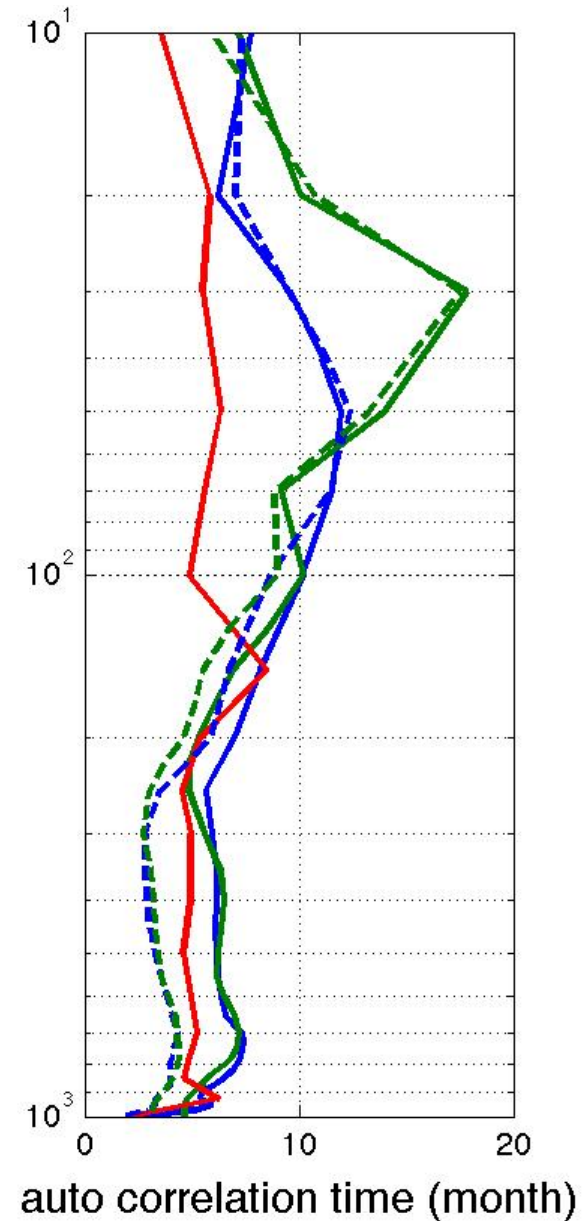
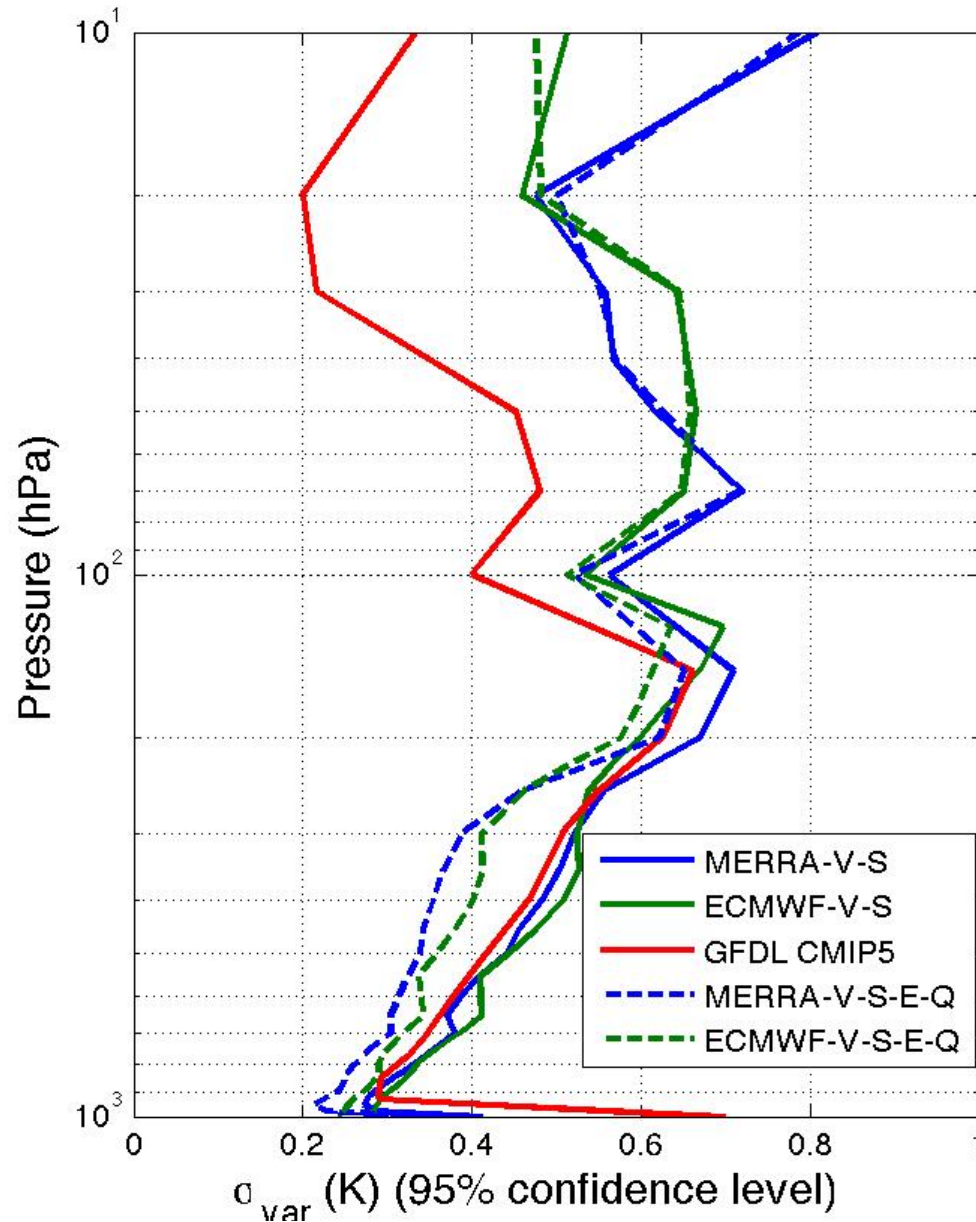


# Surface skin temperature anomaly and linear trend from MERRA and ECMWF



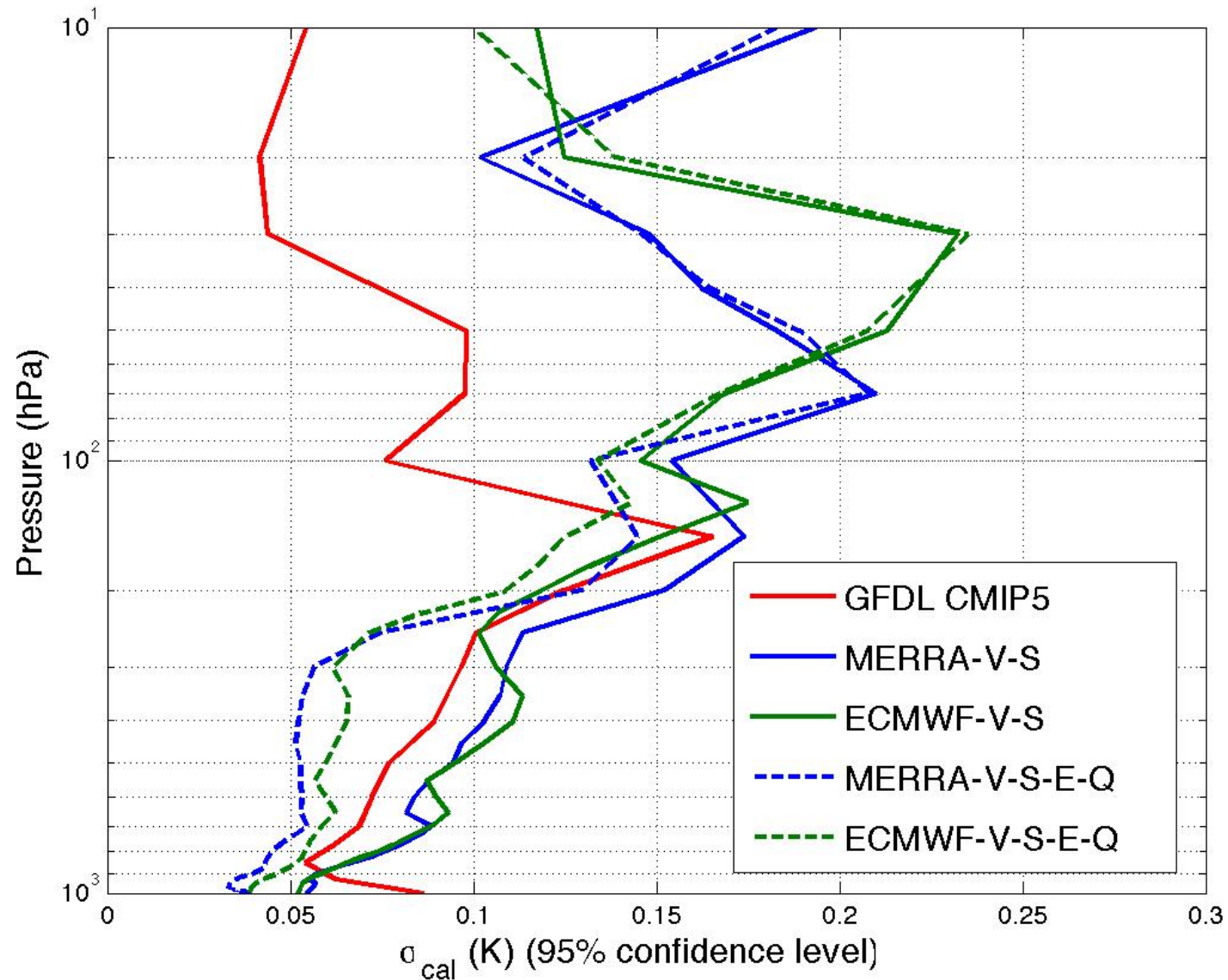


# Temperature variability derived from MERRA, ECMWF and GFDL CMIP5





# Temperature calibration requirement $U_a = 1.2$ , $\tau_{cal} = 5$ years





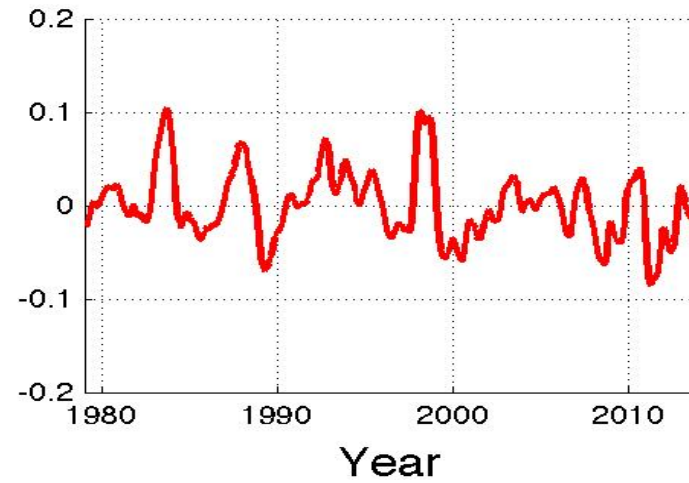
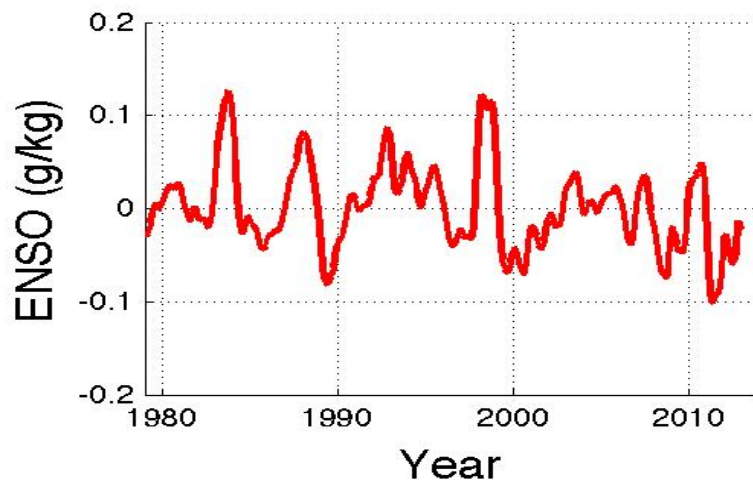
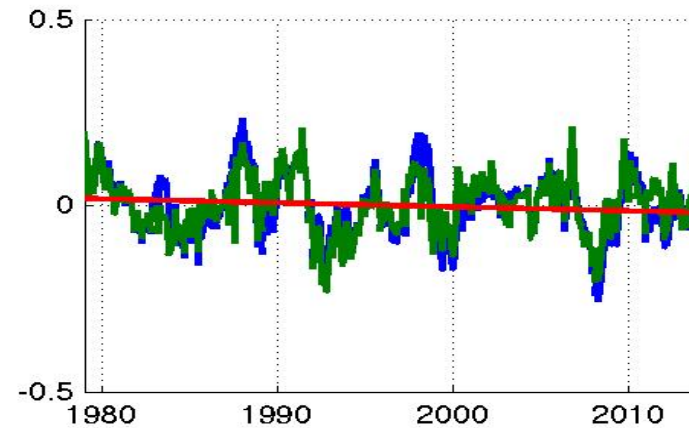
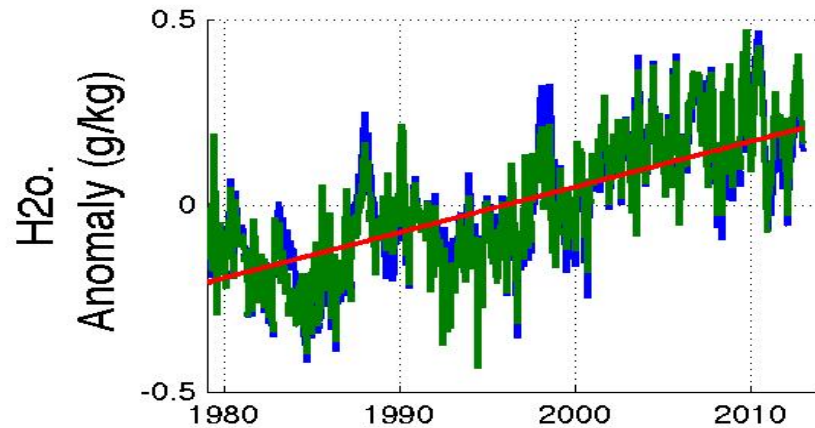
# Statistics of surface skin temperature variability ( $U_a=1.2$ , $\tau_{cal}=5$ years)

Tskin anomaly	$\sigma_{var}$ (K)	$\tau_{var}$ (month)	$\sigma_{cal}$ (K)
ECMWF (free of external forcing)	0.27	4.4	0.045
MERRA (free of external forcing)	0.28	5.1	0.054
GFDL CMIP5 (pi-Control run)	0.31	8.6	0.078
ECMWF (free of all forcing)	0.24	3.1	0.041
MERRA (free of all forcing)	0.24	3.4	0.045





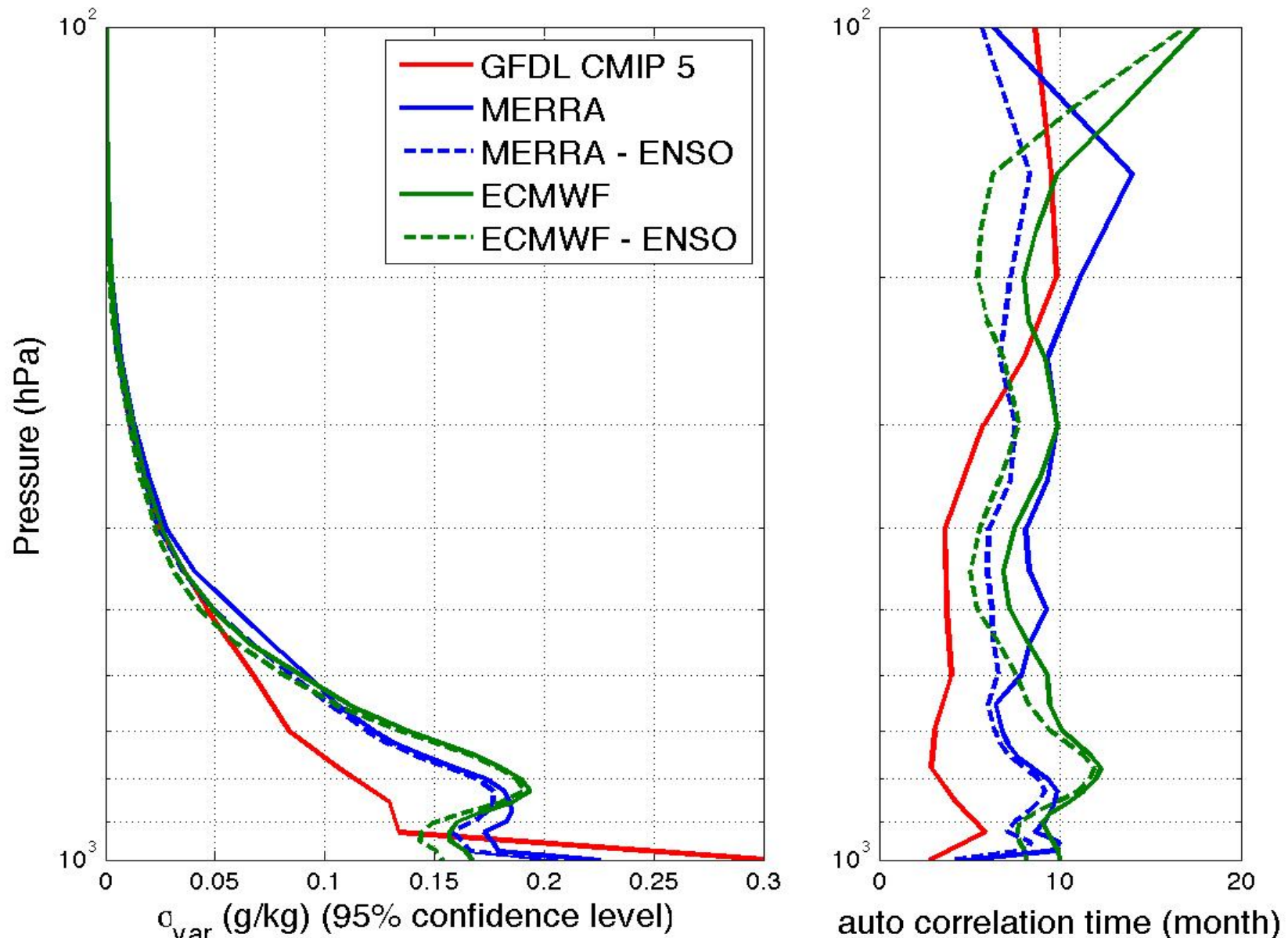
# Global humidity anomaly @ 1000 hPa

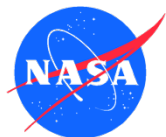


Humidity trend established from MERRA and ECMWF are very different, but magnitude of the internal variation are similar

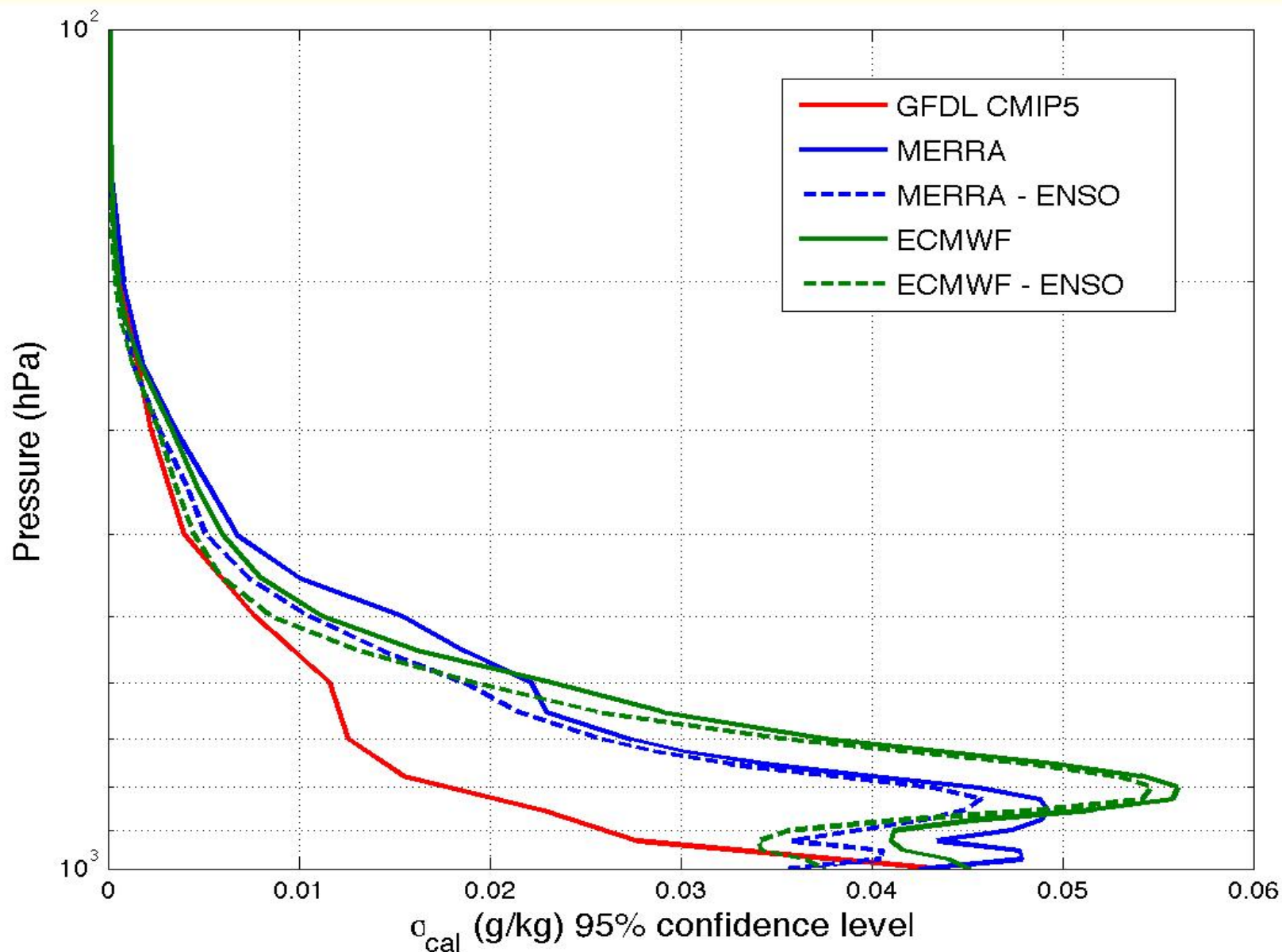


# Humidity variability derived from MERRA, ECMWF and GFDL CMIP5





# Humidity calibration requirement $U_a = 1.2$ , $\tau_{cal} = 5$ years

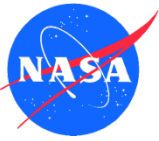






# Summary for natural variability study

- The temperature and the specific humidity variability derived from the long term ECMWF data and that from the long term MERRA data are in similar scale.
- The humidity trend derived from the ECMWF data and that from MERRA data are very different, but the derived variability are similar
- The small natural variability near surface puts a stringent instrument calibration requirement
- Skin temperature requirements derived using MERRA, ECMWF data generally agree with each other



## **Part II**

# **Spectral calibration requirement**



# Attribution of spectral calibration error to geophysical parameters

*Optimal fingerprint attribution*

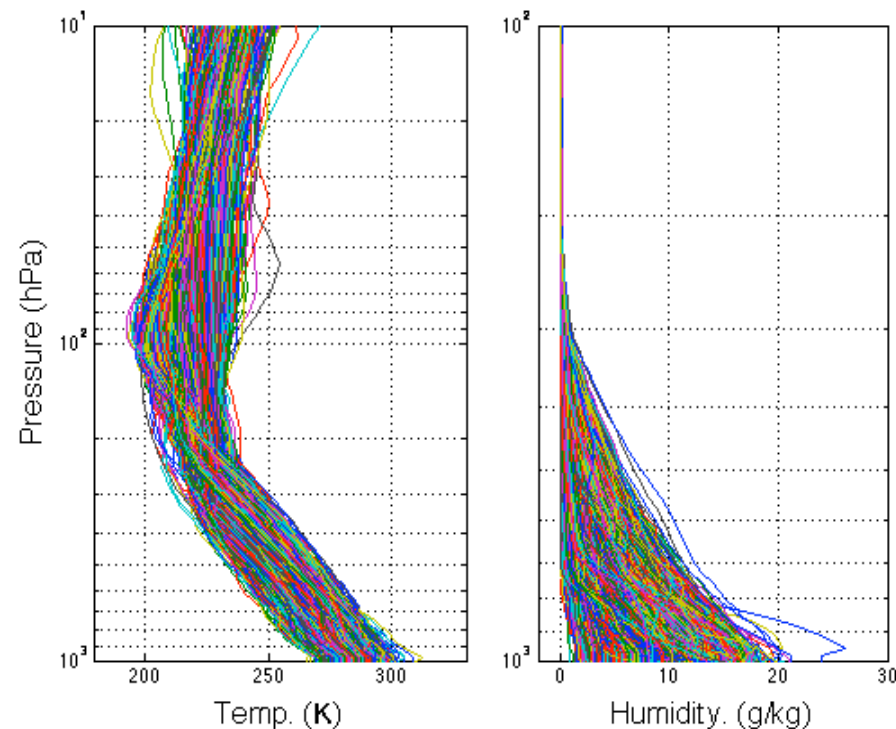
$$\overline{\Delta X} = (\overline{K}^T \Sigma_s^{-1} \overline{K} + \lambda H)^{-1} \overline{K}^T \Sigma_s^{-1} \overline{\Delta R}$$

$\Sigma_s$  the covariance matrix that accounts for various error sources

*Attribution of spectral calibration error*

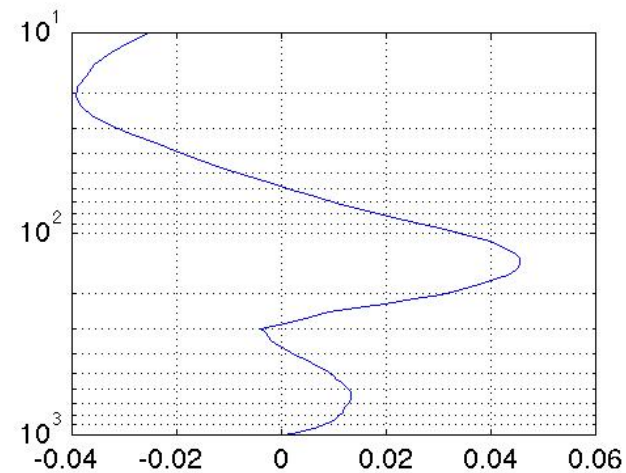
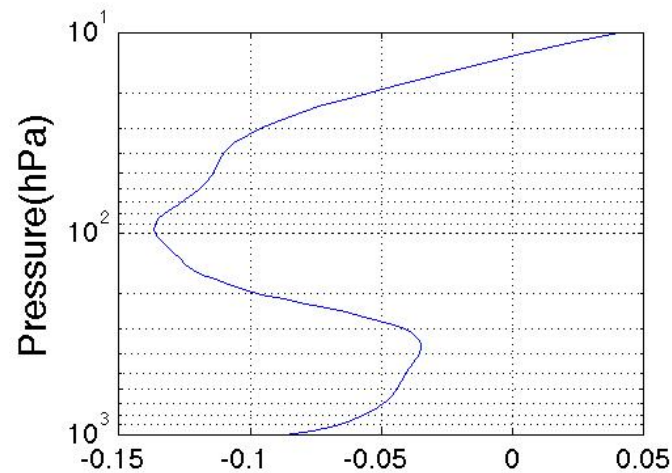
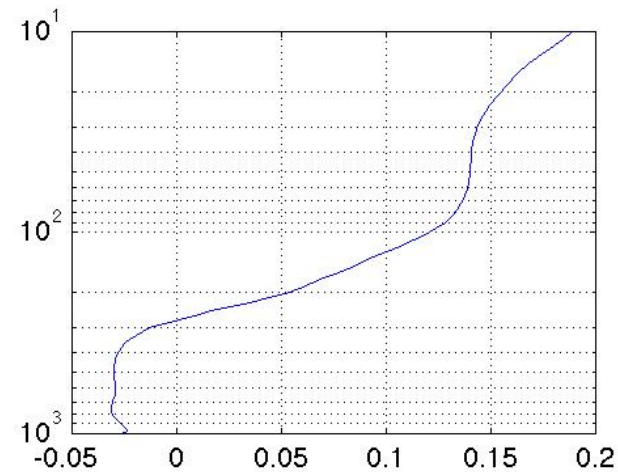
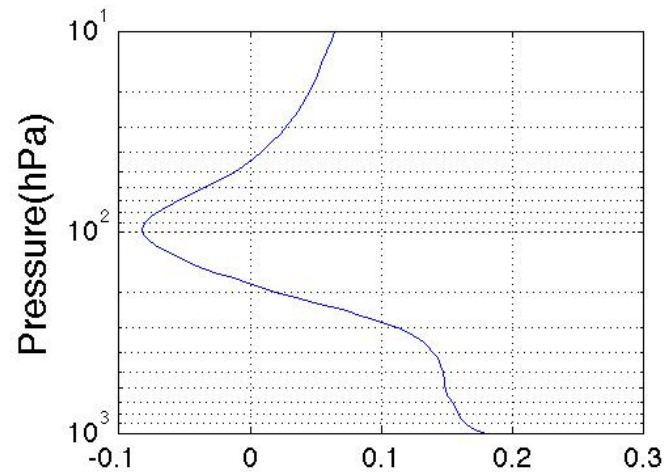
$$\Delta X_{cal} = (\overline{K}^T \Sigma_s^{-1} \overline{K} + \lambda H)^{-1} \overline{K}^T \Sigma_s^{-1} \Delta R_{cal}$$

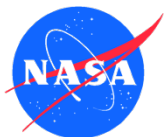
- Globally distributed atmospheric profiles are used in the simulation study
- 100-layers atmosphere used to represent the inhomogeneous vertical thermal structure
- Radiance Spectra simulated using PCRTM with model natural variability included
- The Key to the vertical profile fingerprinting is to use EOF constraint



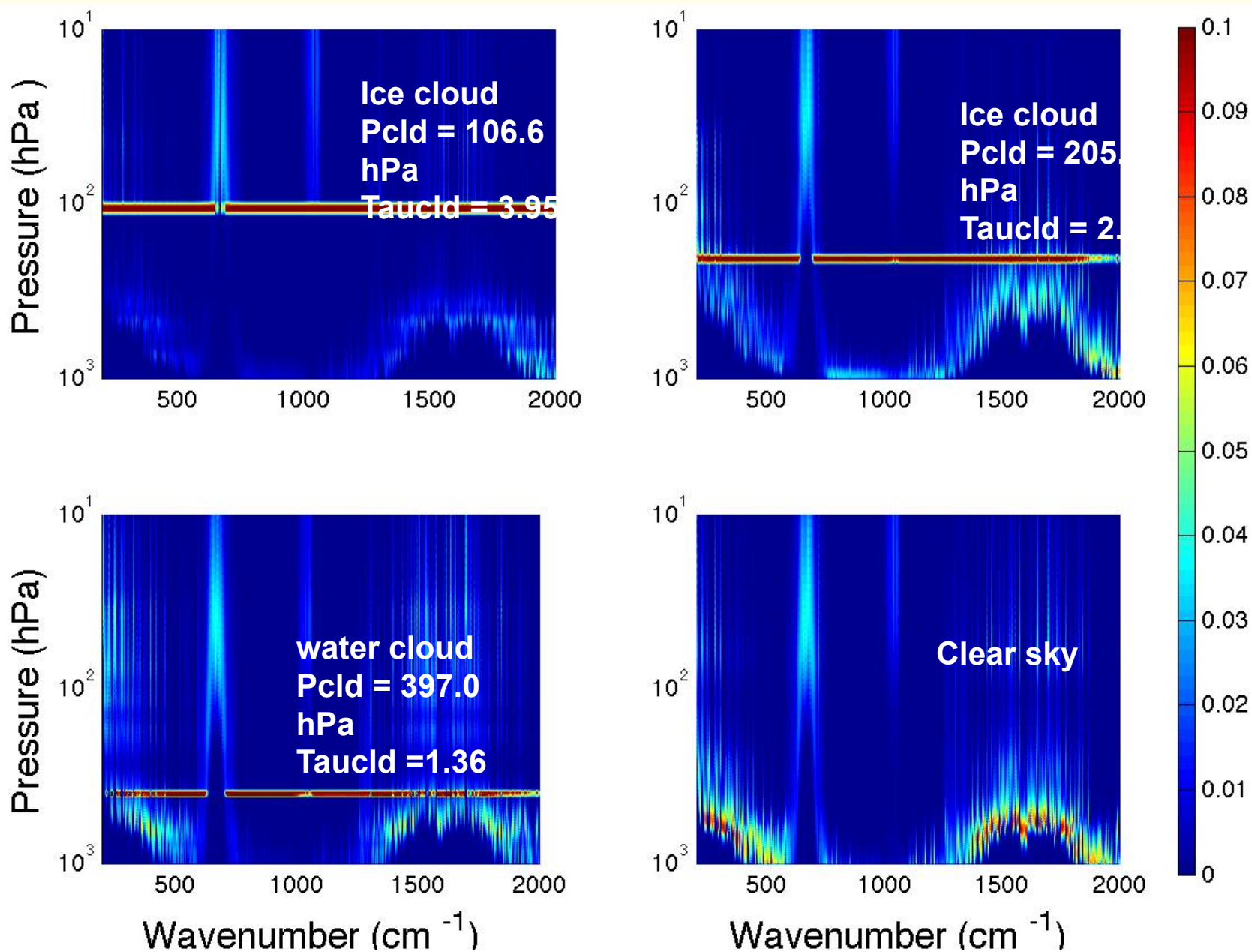


# Example of first four EOFs of atmospheric Temperature Profile

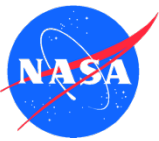




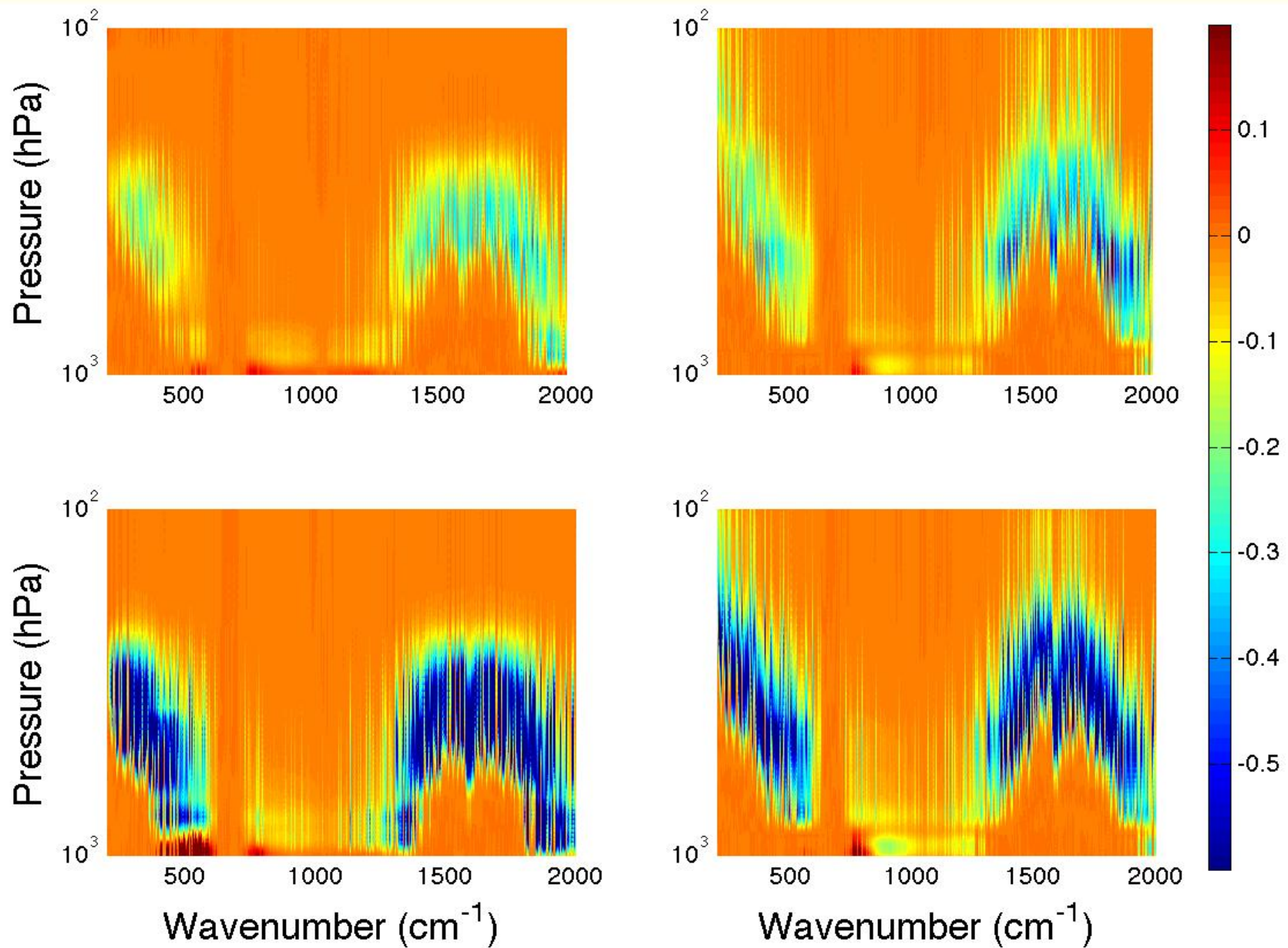
# Temperature Radiative Kernel

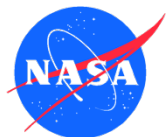




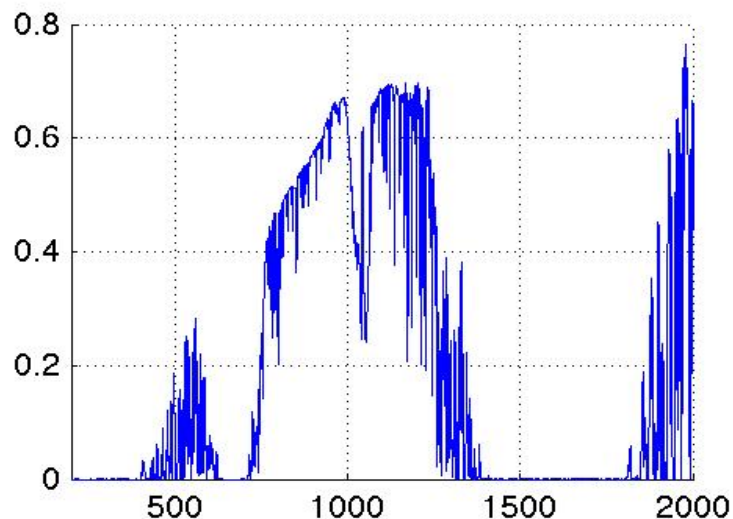
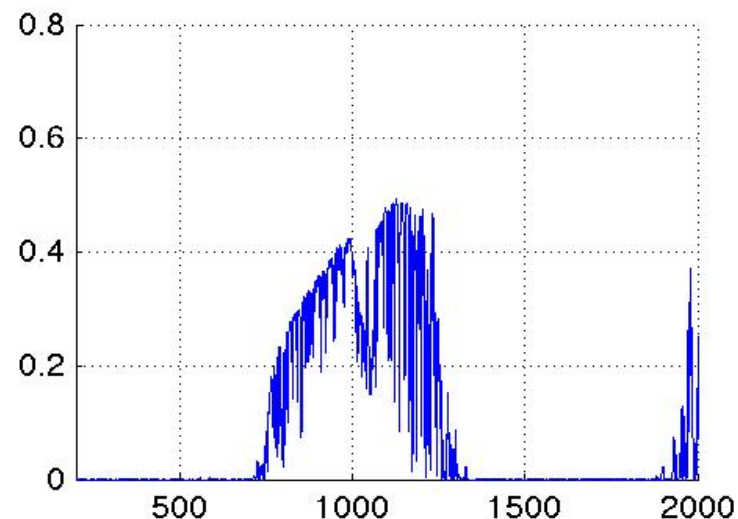
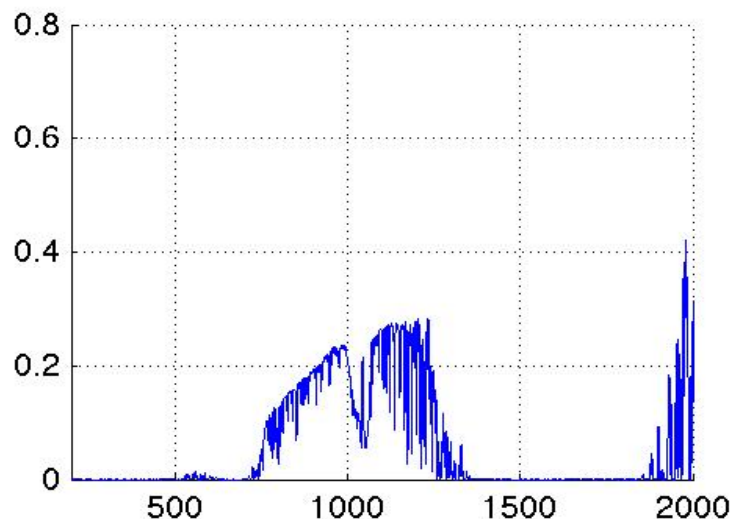


# Humidity Radiative Kernel

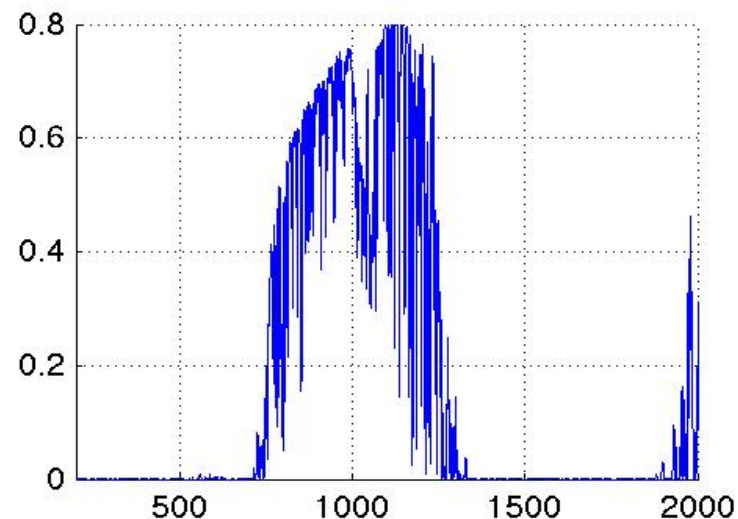




# Surface skin temperature Jacobian

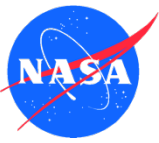


Wavenumber ( $\text{cm}^{-1}$ )

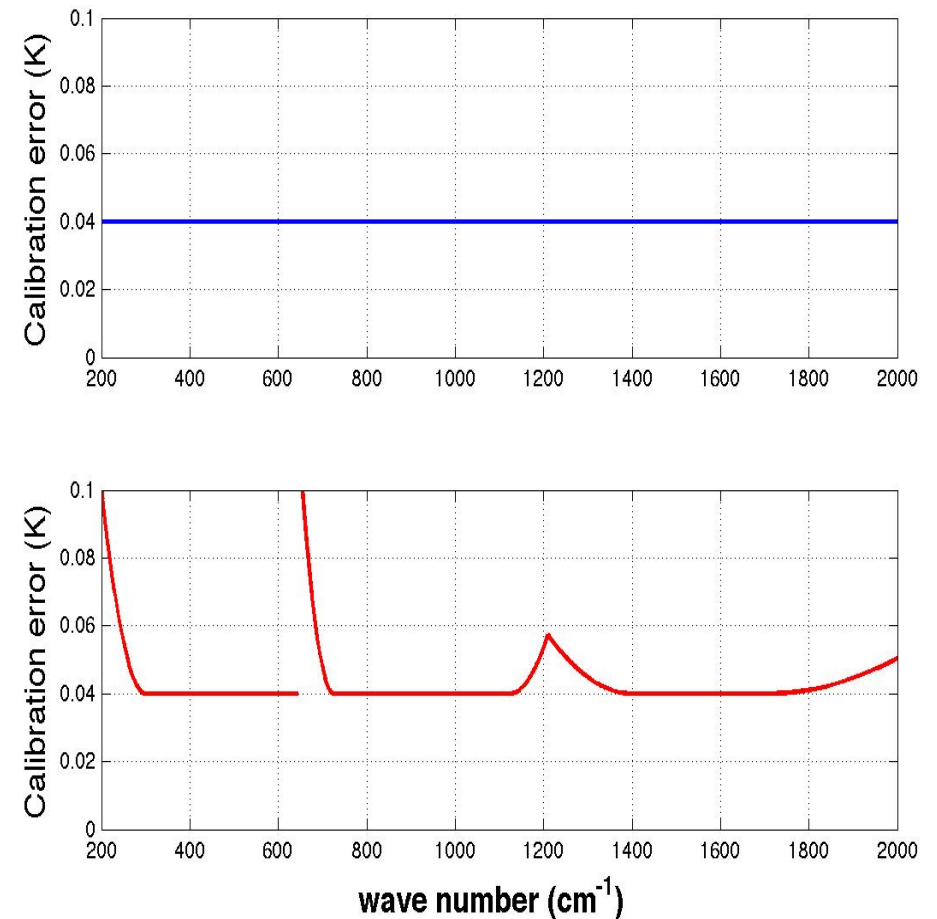
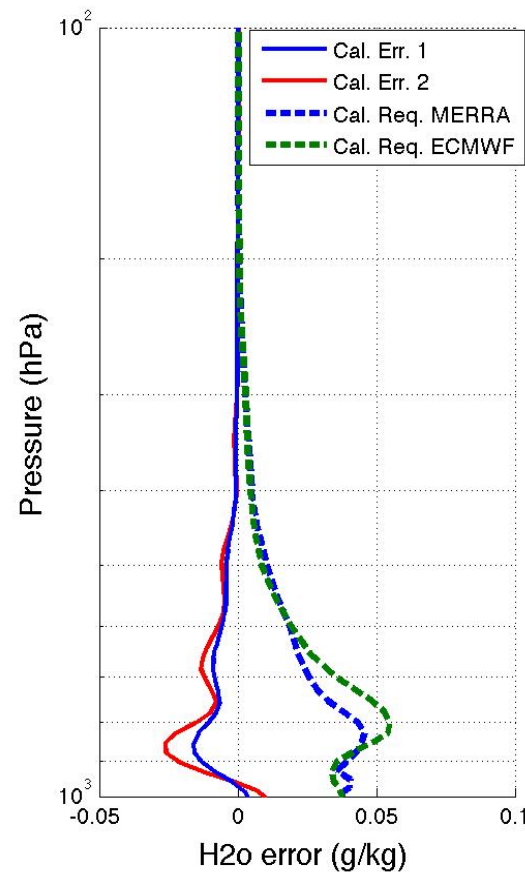
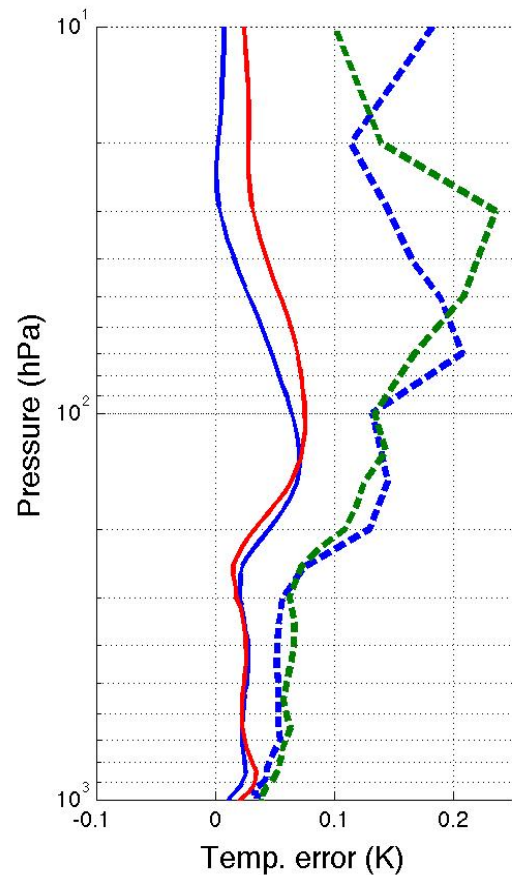


Wavenumber ( $\text{cm}^{-1}$ )





# Spectral calibration errors and the associated error in temperature and humidity observation





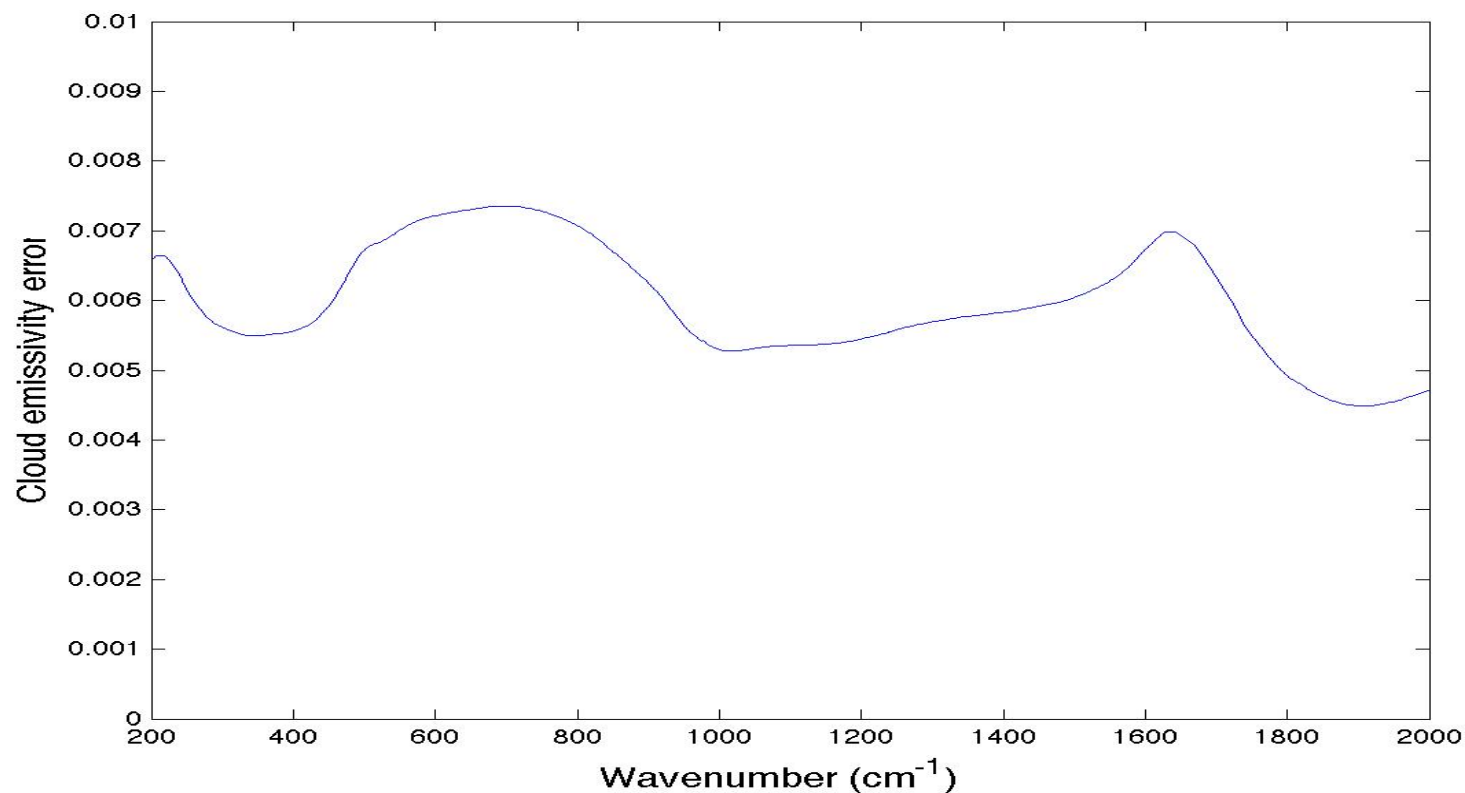
# Spectral information of CLARREO

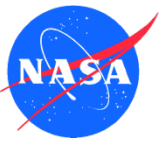
- Similar information is provided by three different spectral regions (in band 1 and band 3)  $200\text{ cm}^{-1} \sim 645\text{ cm}^{-1}$ ,  $1210\text{ cm}^{-1} \sim 1600\text{ cm}^{-1}$ ,  $1600\text{ cm}^{-1} \sim 2000\text{ cm}^{-1}$ .
- Stratosphere temperature observation accuracy is determined by the spectral accuracy of  $\text{CO}_2$  region ( $645\text{ cm}^{-1} \sim 700\text{ cm}^{-1}$ ).
- Information redundancy means the calibration requirement for certain channels can be relaxed, if we de-weight or eliminate the information contribution from the associated channels.
- IR detector tend to have larger calibration error near the band edge. The error around  $200\text{ cm}^{-1}$ , around  $1210\text{ cm}^{-1}$ , around  $2000\text{ cm}^{-1}$  will affect surface to low altitude observation accuracy for both temperature and humidity, depending on how broad the noise spectra extend.



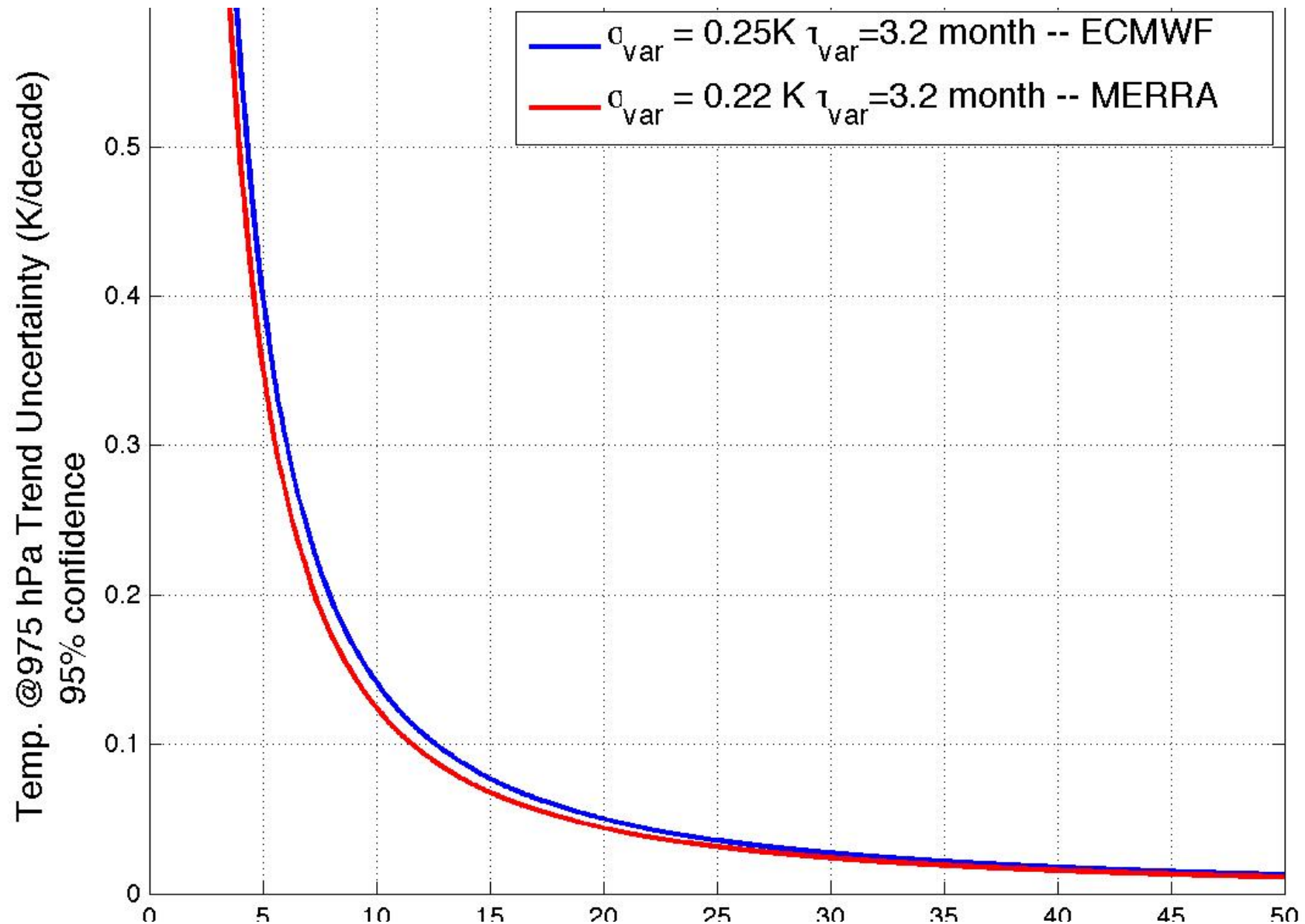
# Error associated with other Parameters introduced by a 0.04K calibration error

	Skin temp. (K)	Cloud optical depth	Cloud particle size ( $\mu\text{m}$ )	Cloud top temp. (K)
$\sigma_{\text{cal}}$	0.04K	< 0.001	< 0.001	0.04K



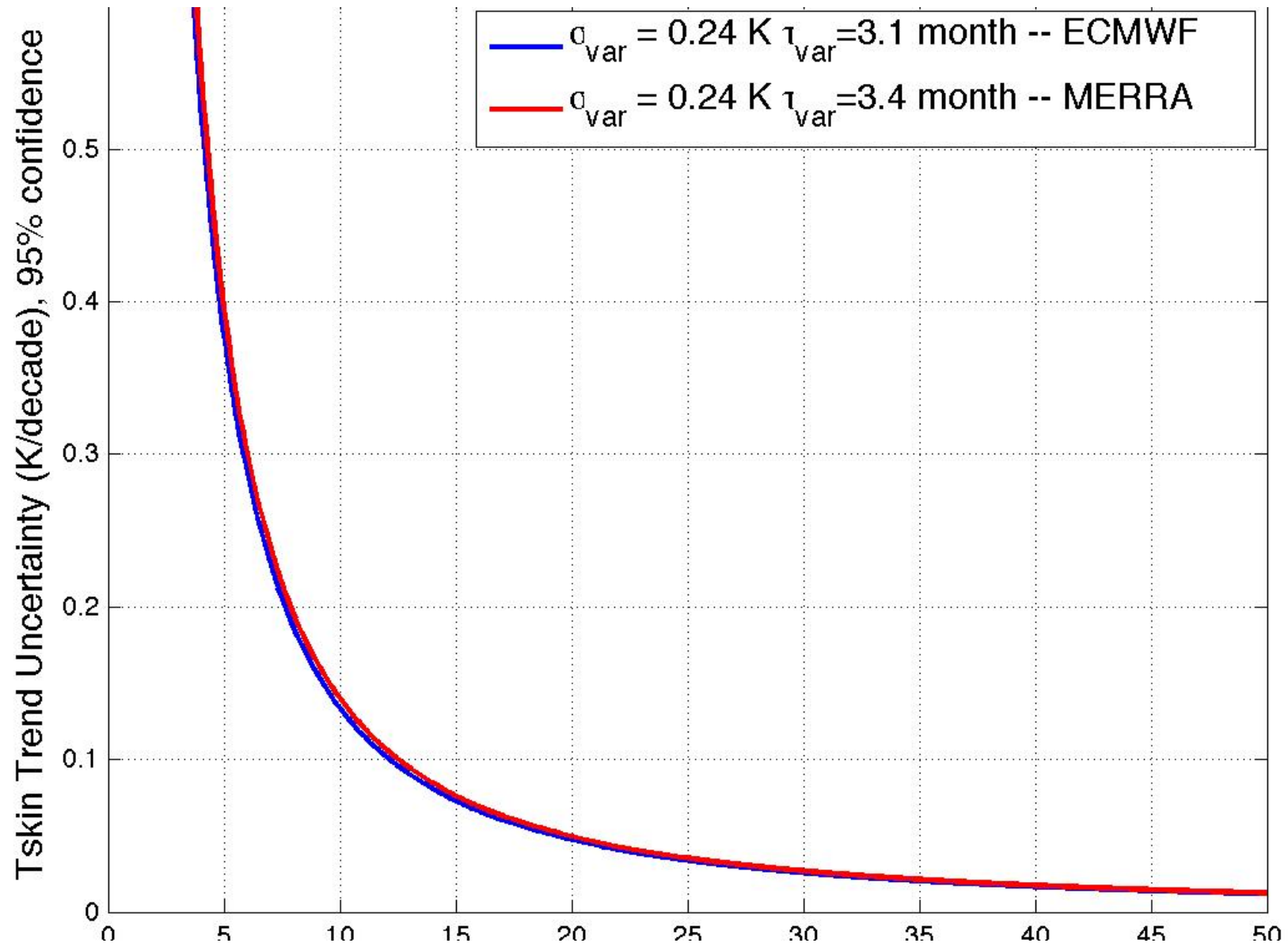


# 975 hPa Trend uncertainty based ECMWF and MERRA natural variability





# Surface Skin Temperature Trend uncertainty based ECMWF and MERRA natural variability





# Summary

- 34 years MERRA and ECMWF reanalysis data provide a consistent evaluation of the natural variability for  $T(p)$  and  $H_2O(p)$
- GFDL CMIP5 climate model gives similar natural variability in the troposphere
- The 0.04K ( $k=2$ ) calibration accuracy is imposed by the requirement of observing the small variation of near surface air temperature
- The 0.04K calibration baseline will serve the purpose of observing the natural variability of
  - Temperature and water vapor vertical profiles
  - cloud properties
  - Surface temperature
- For climate fingerprinting application
  - Larger errors can be tolerated those spectral regions with redundant information
  - Potential larger calibration error at IR detector band edges can be well accommodated thanks to the rich information provided by the hyper-spectral sensor
  - EOF is a good way to constrain vertical correlations of  $T$  and  $H_2O$  profiles in fingerprinting process
- For intersatellite calibration and TOA flux calculations
  - It's better to keep spectral dependent calibration error small